QUANTITATIVE EVALUATION OF THERMALLY INDUCED RESIDUAL STTRESSES IN WHITE CAST IRON AND STEELS WITH DIFFERENT CEMENTITE MORPHOLOGIES

I. Altpeter, R. Kern, M. Lang
Fraunhofer Institut Zerstörungsfreie Prüfverfahren
Universität, Gebäude 37
D-66123 Saarbrücken
Germany

INTRODUCTION

The starting point for this work were damages in rolls of chill casting. Results of damage analysis have shown that the reason for these damages were cracks caused by thermally induced residual stresses [1]. The reason for these microstructural residual stresses is a mismatch in the thermal expansion coefficients between the ferrite and cementite phases. It is well known that the thermal expansion coefficients of the ferrite and cementite phases are identical approaching the Curie-temperature of cementite (T_C=210°C for pure Fe_3C), whereas they are quite different at room temperature (Figure 1) [2,3]. Below the Curie-temperature the thermal expansion of cementite is smaller than that of the ferrite phase.

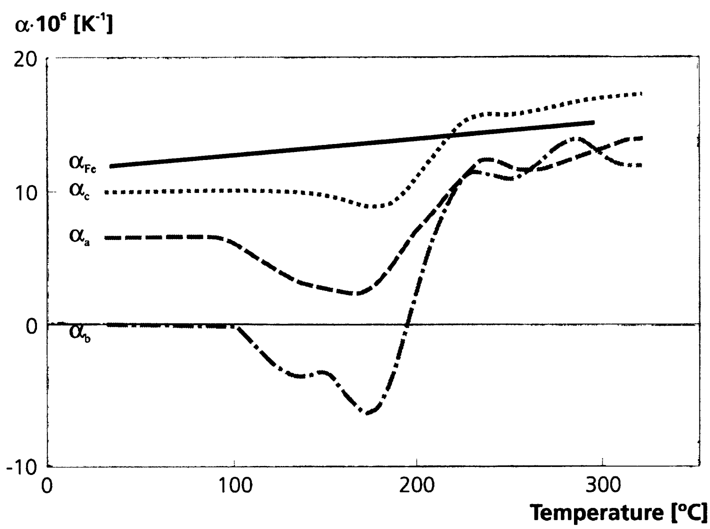

Figure 1. Differential microscopic thermal expansion coefficients of ferrite and for the three crystallographic directions of cementite.

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The goal of this work was to characterize these residual stresses on the basis of the magnetic Barkhausen noise.

BASICS ON THE INFLUENCE OF RESIDUAL STRESSES ON THE MAGNETIC BARKHAUSEN NOISE

The generation of thermally induced residual stresses depends very much on the morphology of the cementite phase in a ferrite matrix. Refering to a theoretical model by Laszlo [4] the second order residual stress field in pearlitic globular microstructure states has a smaller range than in pearlitic lamellar microstructure states. For instance in pearlitic globular and lamellar microstructure states, different residual stresses are to be expected. It is well known that the different types of Bloch-walls can be used as stress sensitive sensors in the ferromagnetic materials [5]. The 90°-Bloch-walls in steels show a direct interaction with stresses. This is caused by the large extent of their residual stress fields in contrast to 180°-Bloch-walls.

Figure 2 shows typical Barkhausen noise curves in comparison with hysteresis loops for pearlitic globular and pearlitic lamellar microstructure states. The Barkhausen noise curve for pearlitic globular microstructures is characterized by double peaks. The first peak can be interpreted as a contribution of the ferrite phase, the second peak as a contribution of the cementite phase.

EXPERIMENTS AND RESULTS

Different steels with globular and lamellar cementite morphology have been investigated as a function of temperature and load stress. The temperature of the specimen has been varied in the range between room temperature and + 250°C. Figure 3 shows M_{MAX} as a function of the temperature for soft iron, white cast iron and two different carbon steels.

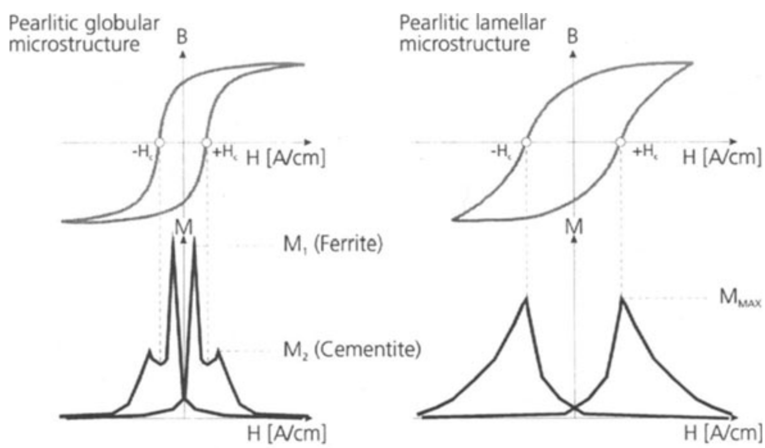

Figure 2. Barkhausen-Noise signal as a function of field strenght compared to the hysteresis loop of pearlitic globular microstructure (left) and of pearlitic lamellar microstructure (right).

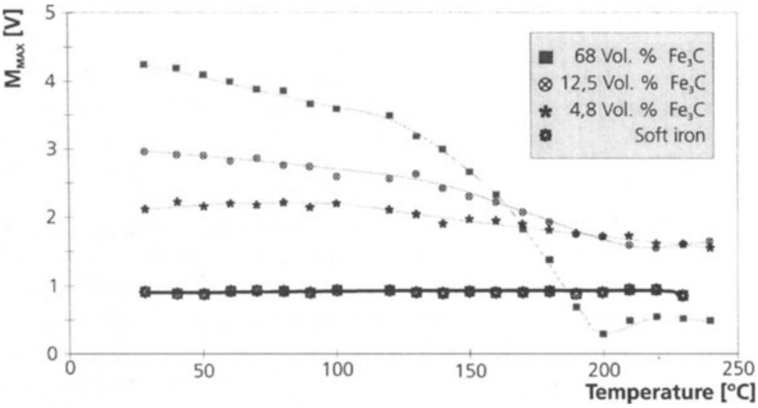

Figure 3. Temperature dependency of the amplitude of the magnetic Barkhausen noise for soft iron, two steels with lamellar pearlitic structure and white cast iron.

As there is no change in M_{MAX} for soft iron with the temperature, there must be another reason for the changes in the other curves. At room temperature M_{MAX} is increasing with increasing cementite content. This can be explained with growing tensile stresses in the ferrite matrix as a function of the cementite content. This was proven by X-ray measurements [3].

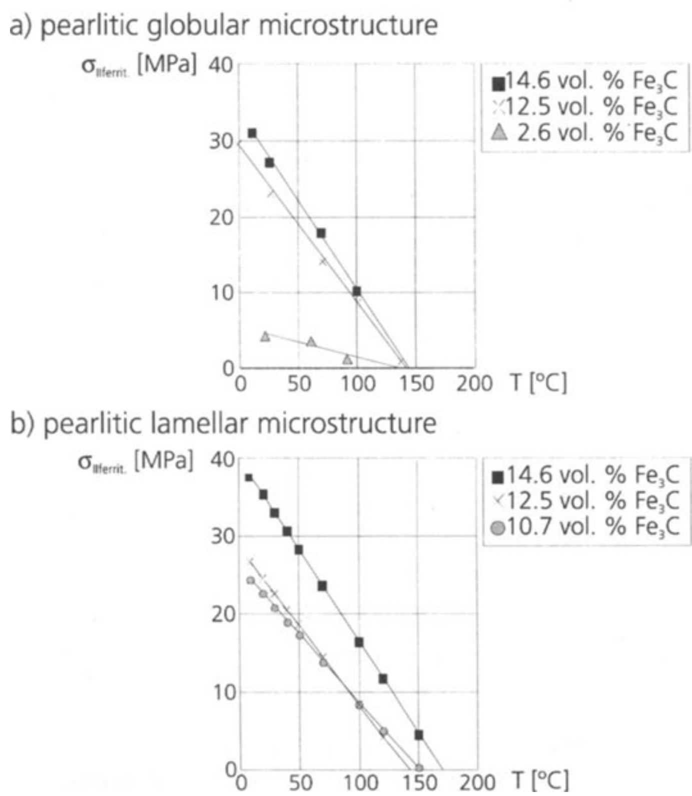

Figure 4. Theoretically determined residual stresses of second kind as a function of temperature in the ferrite phase a) of pearlitic gldular microstructure and b) of pearlitic lamellar microstructure.

Getting closer to the Curie-temperature T_C of cementite in the different materials there is a decline in M_{MAX}. The temperature at which a minimum is observed corresponds to the Curie-temperature T_C. This was shown by Mössbauer-spectroscopy. With increasing temperature, theoretically determined residual stresses of second kind decrease and change from tensile to compressive stress. Figure 4 shows such theoretically expected values as a function of temperature for three steels with different cementite content and morphologies.

To evaluate the residual stresses quantitatively experiments were carried out varying the loading stresses applied to the specimens. Due to the magnetostrictive effect, the M_{MAX} (σ) curve shows a maximum at a certain stress-value. The stress at which this maximum occurs is constant regarding it as the total sum of all residual and loading stresses. A change in the loading stress value for this maximum therefore indicates the same change in the residual stresses. There are different ways to use this effect to determine the residual stress value. One is to evaluate the difference in the loading stress at which the maximum in M_{MAX} occurs at room temperature and at the Curie-temperature T_C.

Two-Step-Model

To start, M_{MAX} is measured at room temperature with no loading stress applied. Then in the first step the specimen is heated up to the Curie-temperature T_C. In the second step increasing tensile loading stress is applied to the specimen until M_{MAX} reaches the value it had at room temperature. The stress $\Delta\sigma$ necessary to reach this value is equivalent to the thermally induced residual stresses that were eliminated by heating the specimen up to T_C. The principles of this two-step-model are illustrated in Figure 5.

The values found by using this model correspond very well both with theoretically expected values and values that were received by X-ray measurements. It has to be mentioned that the error bars using X-ray are significant and that X-ray measurements require a minimum amount of cementite to get peaks that can be analysed.

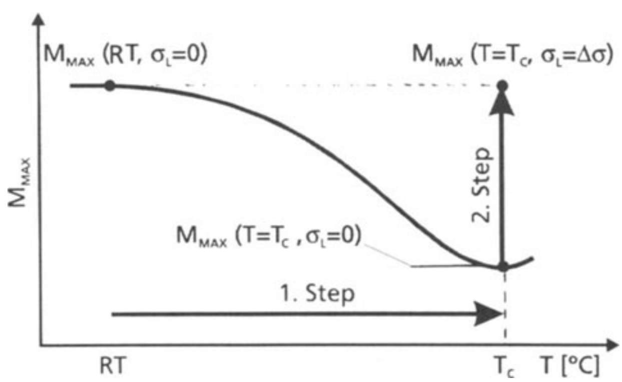

Figure 5. Two-Step-Model to evaluate thermally induced residual stresses.First the specimen is heated beyond the Curie-temperature T_C of the corresponding cementite phase and the maximum Barkhausen noise amplitude M_{MAX} is measured as a function of the materials parameters. Second, the specimen is loaded with increasing tensile stress at T=T_C until M_{MAX} reaches its former value at RT. This stress load value corresponds with the thermally induced second order residual stresses at RT.

Future Work

On the one hand, this technique will be verified at other steel grades with different cementite contents and at a steel tending to Cu-precipitations while being in service at temperatures around 350 °C.

On the other side the principle potential of the magnetic Barkhausen noise towards the early detection of H-induced stress corrosion cracking (HISCC) was already shown [6]. As it is planned to extend these investigations to in fact realistic materials it will be examined whether the two-step-model presented in this paper will also bring proper results in that area of application.

CONCLUSION

A two-step-model for the detection of second order residual stresses in low carbon steels and white cast iron was presented. It is based on the influence of microstresses from second phases on the magnetic Barkhausen noise. The shape of the Barkhausen noise curve provides information about the cementite morphology. The experimentally evaluated and theoretically predicted stress values of thermally induced second order residual stresses are comparing well in steel grades with different cementite morphologies and cementite content.

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